ROSAT **PSPC**

Calibration Corrections Applied to Individual PSPC Events

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SUMMARY

This document gives a summary of all the calibration corrections applied to individual PSPC events during their conversion from their arrival position & pulse height (PH) channel to their corrected coordinates & pulse-invariant (PI) channel.
This memo is essentially a copy of the original MPE memo TN-ROS-ME-ZA00/027 (Hasinger & Snowden, 1990), but updated and expanded to refer to the FITS versions of the calibration files available from the HEASARC.
Intended Audience: ROSAT GOF and HEASARC programmers.

LOG OF SIGNIFICANT CHANGES

Release Date	**Sections Changed**	**Brief Notes**
1995 Sep 21		Internal Draft
1995 Oct 13		First Public Release
2012 Aug 31	all	Minor corrections by MFC

1 INTRODUCTION

Each event detected in the *ROSAT* PSPC is tagged onboard with a number of pieces of information, including its arrival time, its position and its nominal pulse height. On the ground this information is transfered to the 'Event File' in the columns `TIME`, `RAWX` & `RAWY`, and `PHA` respectively (for files in RDF format – see Table 1 for the corresponding column names for earlier formats).

However, to facilitate data analysis, the Standard Analysis Software System (SASS) applies corrections for a number of effects. Here we describe the corrections required to convert from the raw detector coordinates of an event to the linearized detector coordinates, and from the observed pulse-hight channel of an event to the pulse-invariant (PI) channels. These corrected values are then also transferred and stored in the `DETX`, `DETY` & `PI` columns of the Event file (Table 1), respectively.

These corrections are applied within the SASS processing and have been described in the MPE Memo TN-ROS-ME-ZA00/027 "Calibration Corrections to individual PSPC events" (Hasinger & Snowden, 1990).

1.1 Overview of Inputs & Outputs

The corrections described in this memos are performed on an event-by-event basis, using the following observed ('raw') parameters from the Event file:

- observed PH bin of each event
- observed X & Y coordinates of each event in raw detector coordinates
- time-tag for each event

and producing the following corrected/derived parameters, which are written back into the Event file:

- corrected pulse invariant bin PI of each event
- corrected coordinates X_3 & Y_3 of each event

The names of the columns used to store these parameters in the various FITS file formats used for *ROSAT* PSPC data are summarized in Table 1. However readers are reminded

Table 1: Column Names used to store the i/p & o/p parameters

Parameter		**FITS File Format**		
Symbol	**Description**	**RDF**	**US-Rev0**	**German-Rev0**
Input Parameters				
t	Time-tag of event	`TIME`	`TIME`	`TIME`
X	Raw X-axis position	`RAWX` †	–	–
Y	Raw Y-axis position	`RAWY` †	–	–
PH	Raw pulse-height bin	`PHA`	`PHA`	`RAW_AMPL`
Output Parameters				
X_3	Linearized X-axis position	`DETX`	`DX`	`XDET`
Y_3	Linearized Y-axis position	`DETY`	`DY`	`YDET`
PI	Derived pulse-invariant channel	`PI`	`PI`	`AMPL`

† - available in the `*_raw.fits` file

that all PSPC datasets available from the HEASARC archives have been converted to RDF format.

2 THE CORRECTIONS

2.1 Correction for non-linearities in the ADC

The ADC (analogue-to-digital converter) within the PSPC electronics introduces small variations ($< 3\%$) in the width of the PH channels. The effective width of each channel has therefore been determined from a large number of ground calibration measurements and subtracting a smooth spline function.

Inputs & Outputs

Inputs:

- observed PH bin of each event (from Event file)
- lower & upper boundaries (ADC_1 & ADC_2) on each effective ADC bin (from Calibration file)

Outputs:

- effective PH bin, PH_1, for each event

Method

The non-linearity of the ADC is corrected by drawing a random number $RAN(0,1)$ between zero and one, and calculating the effective PH bin, PH_1 from the observed PH bin as follows:

$$PH_1 = ADC_1(PH) + RAN(0,1) \times (ADC_2(PH) - ADC_1(PH)) \tag{1}$$

Files

- **SASS**:
  The effective boundaries of each channel are stored in a calibration file: `ADC_BINS.DAT`, which is a simple ASCII table with 256 rows, each row containing the two reals giving the lower (ADC_1) & upper (ADC_2) boundaries of the effective channel. The SASS subroutine which uses this is `CADC` (within CT module).
- **CALDB**:
  The effective boundaries of each channel are stored in the calibration file: adc_bins.fits
  Format: FITS BINTABLE, with 256 rows, and 3 columns where:
  - column `PH_1` gives PH_1 corresponding to `ADC_LO`
  - column `ADC_LO` gives ADC_1
  - column `ADC_HI` gives ADC_2

Notes

In the MPE Memo TN-ROS-ME-ZA00/027 "Calibration Corrections to individual PSPC events" (Hasinger & Snowden, 1990), this correction is described in slightly different terms. A different input calibration file is described, which contains the lower edge ADC_1 along with the width of each bin (instead of the upper edge, ADC_2, described above). Clearly this is a minor difference, and presumably reflects a change made to SASS sometime after 1990.

2.2 Correction for saturation of the detector gain

For high energy photons, the gain of the PSPC detector begins to saturate (*ie* there is a fall-off in the signal amplication and a loss of linearity between incident photon energy and channel). This is a relatively minor effect, only noticeable above ~1 keV and has been modelled using ground calibration measurements.

Inputs & Outputs

Inputs:

- effective PH bin, PH_1, for each event (after correction described in Section 2.1)
- channel,B_{Al}, in which the peak of the onboard Al calibration source is expected to occur (interpolating between the nearest two measurements to the time of the observation)
- Algorithm and associated parameters to perform correction (the coefficients C_1, C_3, defined below)

Outputs:

- corrected PH bin, PH_2, for each event

Method

The corrected PH bin, PH_2 is constructed as follows:

$$PH_2 = \begin{cases} PH_1 & \text{if } PH_1 < C_2 \\ PH_1 + C_1 \times (PH_1 - C_2)^{C_3} & \text{otherwise} \end{cases} \tag{2}$$

with

$$C_2 = 0.62777 \times B_{AL} + 4.453 \tag{3}$$

where B_{Al} is the channel in which the peak of the line from the onboard Al calibration source is expected to lie. B_{Al} is calculated by (linearly) interpolating between the results from Prescott fits to the Al calibration observations immediately before & after the observation. For the *nominal* gain, $B_{AL} \simeq 151$, giving $C_2 \simeq 99$ (equivalent to ~ 1 keV).

Files

- **SASS**:
  The coefficients are hard-wired into the code in the SASS subroutine `CGS` (within CT module) with the following values:
  $C_1 = 5.5 \times 10^{-2}$
  $C_3 = 1.74$
  along with equation 3.
- **CALDB**:
  The values of the coefficients C_1 & C_3 are currently not available in the CALDB
  The results of the Prescott fits to observations using the Al calibration source are stored in the calibration files: `alkhist_v1_b.fits` and `alkhist_v1_c.fits` (for PSPCB & PSPCC respectively)
  Format: FITS BINTABLE, with several columns, the most important of which are:
  - column `ISCC` giving the time, as measured by the spacecraft clock, of each observation using the Al calibration source
  - column `ALK_BIN` the peak of the onboard Al calibration source based upon Prescott fits (in cases where more than one Al calibration observation was carried out on a given day, the value stored in `ALK_BIN` is the mean). Interpolating between the nearest two values in `ALK_BIN` for a given observation date gives B_{Al}.

2.3 Temporal Gain Correction

The gain (*ie* pulse hight as a function of energy) of the PSPC changes slowly due to variations in gas density, composition, high voltage, pressure and temperature. The temporal gain $G(t)$ is measured by fitting Prescott functions to the data regularly obtained from the on-board Aluminum K_α calibration source.

Inputs & Outputs

Inputs:

- effective PH bin, PH_2, for each event (after correction described in Section 2.2)
- channel,B_{Al}, in which the peak of the onboard Al calibration source is expected to occur (interpolating between the nearest two measurements to the time of the observation)

Outputs:

- corrected PH bin, PH_3, for each event

Method

The corrected PH bin, PH_3, is given by:

$$PH_3 = PH_2 \times (D_0 + D_1 \times B_{AL} + D_2 \times B_{AL}^2 + D_3 \times B_{AL}^3) \quad (4)$$

where
$D_0 = 4.543085$
$D_1 = -5.135878 \times 10^{-2}$
$D_2 = 2.518324 \times 10^{-4}$
$D_3 = -4.562700 \times 10^{-7}$
and B_{Al} is the channel in which the peak of the line from the onboard Al calibration source is expected to lie. B_{Al} is calculated by (linearly) interpolating between the results from Prescott fits to the Al calibration observations immediately before & after the observation.

Files

- **SASS**:
  The coefficients D_0–D_3 are hard-wired into the code in the SASS subroutine `CTG` (within CT module) along with equation 4.
- **CALDB**:
  The values of the coefficients D_0–D_3 are currently not available in the CALDB
  The results of the Prescott fits to observations using the Al calibration source are

stored in the calibration files: alkhist_v1_b.fits and alkhist_v1_c.fits (for PSPCB & PSPCC respectively)
Format: FITS BINTABLE, with a number of columns, the most important of which are:

- column `ISCC`: the time, as measured by the spacecraft clock, of each observation using the Al calibration source
- column `ALK_BIN`: the peak of the onboard Al calibration source based upon Prescott fits (in cases where more than one Al calibration observation was carried out on a given day, the value stored in `ALK_BIN` is the mean). Interpolating between the nearest two values in `ALK_BIN` for a given observation date gives B_{Al}.

2.4 Electronic Position Correction

The electronic correction removes the small-scale nonlinearities which are introduced by the PSPC wires. This correction can be measured and applied to the X & Y positions of an event independently, but in both cases is a function of pulse-height.

Inputs & Outputs

Inputs:

- observed X & Y coordinates of each event in detector coordinates (from Event file)
- effective PH bin, PH_3, for each event (after correction described in Section 2.3)
- the functions R_1, R_2 & R_3, and S_1, S_2 & S_3 defined below

Outputs:

- corrected positions X_1 & Y_1 of each event

Method

The correction is calculated from the pulse-height (after application of the temporal gain correction) using a parabola. The corrected position along the X-axis is then calculated using:

$$X_1 = R_3(X) + R_2(X) \times PH_3 + R_1(X) \times (PH_3)^2 \tag{5}$$

and the corrected position along the Y-axis using:

$$Y_1 = S_3(Y) + S_2(Y) \times PH_3 + S_1(Y) \times (PH_3)^2 \tag{6}$$

Files

- **SASS**:
  The SASS subroutine which performs this is `DCORE` (within CT module).
- **CALDB**:
  No files currently available

2.5 Spatial Gain Correction

The spatial gain correction (SGC) corrects for variations in the gain due to variations in the distance between the anode wires. This correction is therefore only dependent on the Y-coordinate of each event.

Inputs & Outputs

Inputs:

- Y-coordinate Y_1 of each event (after correction described in Section 2.4)
- effective PH bin, PH_3, for each event (after correction described in Section 2.3)
- the functions L, H_A & H_F defined below (from Calibration files)

Outputs:

- corrected pulse invariant bin PI of each event

Method

The correction can be separated into a position-dependent low-frequency term (L) and two high-frequency terms – one energy-dependent (H_A), and one position-dependent (H_F). The amplitude of H_A is assumed to be a smooth function of the penetration depth. The pulse-invariant PI bin is calculated using:

$$PI = \frac{PH_3}{L(Y_1) + H_A(PH_3) \times H_F(Y_1)} \tag{7}$$

The shape of H_A is calculated from measurements at 1.49 keV and thus is normalized to unity at this energy.

Files

- **SASS**:
  The position-dependent terms L and H_F are stored in calibration files: GAIN_KOR3_B.FITS and GAIN_KOR3_C.FITS (for PSPCB & PSPCB respectively) which are simple ASCII tables with 800 rows, each row containing the two reals giving the lower L & H_F.
  The energy-dependent term H_A is stored in the calibration file `GNAMPL_NEW.DAT` which is a simple ASCII table with 256 rows, each row containing a single real representing H_A.
  The SASS subroutine which uses this is `DCORG` (within CT module).

- **CALDB**:
  The values of the position-dependent terms L and H_F are stored in a calibration files: `gain_kor3_b.fits` and `gain_kor3_c.fits` (for PSPCB & PSPCB respectively)
  Format: FITS BINTABLE, with 800 rows, and 3 columns where:

  – column `Y_1` gives Y_1
  – column `SGC_LF_Y` gives L for the position Y_1
  – column `SGC_HF_Y` gives H_F for the position Y_1

  The values of the energy-dependent term H_A are stored in a calibration file: `gnampl_new.fits` (valid for both PSPCs)
  Format: FITS BINTABLE, with 256 rows, and 2 columns where:

  – column `PH_3` gives PH_3
  – column `SGC_HF_E` gives H_A for the value of PH_3

Notes

SASS has been applying the spatial-gain correction based upon the electronically-corrected X coordinate, and this introduced spurious variations in PI channel, as the electronically-corrected Y coordinate should have been used. The `ftools/rosat` task `pcpicor` recalculates the event file PI column using the Y coordinate.

In the MPE Memo TN-ROS-ME-ZA00/027 "Calibration Corrections to individual PSPC events" (Hasinger & Snowden, 1990), calibration files with different names are referred as being used by SASS. However the memo implies their contents are the same as that described above, hence the name change presumably reflects a change made to SASS and/or the stored values sometime after 1990.

2.6 Window Correction

The window correction removes the large-scale distortions due to the bulging of the detector window as a result of the internal gas pressure versus the external vacuum.

Inputs & Outputs

Inputs:

- coordinates X_1 & Y_1 of each event (after corrections described in Section 2.4)
- PI bin, PI, for each event (after correction described in Section 2.5)
- the functions G_A, G_X & G_Y defined below

Outputs:

- corrected coordinates X_2 & Y_2 of each event

Method

The correction is both a function of position and energy, but it is assumed that these components can be separated into separate terms. The energy-dependent term G_A is assumed to be a smooth function of penetration depth. The shape of the Golden Disk is taken from measurements at 0.93 keV, thus G_A is normalized to unity at this energy. The corrected position along the X-axis is then calculated using:

$$X_2 = X_1 - G_A(PI) \times G_X(X_1, Y_1) \tag{8}$$

and the corrected position along the Y-axis using:

$$Y_2 = Y_1 - G_A(PI) \times G_Y(X_1, Y_1) \tag{9}$$

Files

- **SASS**:
  The SASS subroutine which performs this correction is `DCORW` (within CT module).
- **CALDB**:
  The values of the energy-dependent term G_A are stored in a calibration file: `scal3.fits`
  Format: FITS BINTABLE, with 256 rows, and 2 columns where:
  - column `PI` gives PI
  - column `WC_GA_E` gives G_A for the value of PI

  The values of the position-dependent terms G_X & G_Y are stored in calibration files: `tab`i`_093_`j`.fits`, where i = `x` or `y` for G_X & G_Y respectively, and j = `b` or `c` for PSPCB & PSPCC respectively.
  Format: FITS IMAGE array of dimensions 512×512, where
  - axis-1 X_1
  - axis-2 Y_1
  - stored value is G_X or G_Y

Notes

In the MPE Memo TN-ROS-ME-ZA00/027 "Calibration Corrections to individual PSPC events" (Hasinger & Snowden, 1990), the sign of the correction vectors G_X & G_y is in the opposite sense to that given in equations 8 & 9 (*ie* TN-ROS-ME-ZA00/027 implies the values in G_X are -1 times those actually stored in the calibration files). This presumably reflects a change made to SASS and/or the stored values sometime

2.7 Plate-scale Non-linearities

The plate-scale varies slightly across the field-of-view due to the use of the (essentially) flat detector compared to the curved surface representing the points at which the XRT is perfectly focussed.

Inputs & Outputs

Inputs:

- coordinates X_2 & Y_2 of each event (after corrections described in Section 2.6)
- location (X_{opt},Y_{opt}) of the XRT optical axis in detector coordinates,
- algorithms and coefficents listed below

Outputs:

- corrected coordinates X_3 & Y_3 of each event (the linearized detector coordinates, stored in the `DETX` & `DETY` columns of the Event file – Table 1).

Method

The effect of this has been simulated by ray-tracing experiments to give the shift in the centre-of-mass of the point-spread-function as a function of off-axis angle.

$$X_3 = X_{opt} + R \times \cos\delta\phi \tag{10}$$

$$Y_3 = Y_{opt} + R \times \sin\delta\phi \tag{11}$$

where

$$R = r - (4.1305 \times 10^{-2} \ \times \ r^{0.63}) \tag{12}$$

$$r = \sqrt{(\delta X)^2 + (\delta Y)^2} \tag{13}$$

$$\delta X = X_2 - X_{opt} \tag{14}$$

$$\delta Y = Y_2 - Y_{opt} \tag{15}$$

$$\delta\phi = \arctan\frac{\delta Y}{\delta X} \tag{16}$$

and (X_{opt},Y_{opt}) is the position of the optical axis in detector coordinates, where
$X_{opt} = 4119.0$
$Y_{opt} = 3929.0$

Files

- **SASS**:
  The SASS subroutine which performs this correction is `FCOR` (within CT module).
- **CALDB**:
  No files currently available

REFERENCES

G. Hasinger and S Snowden, 1990 TN-ROS-ME-ZA00/027